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Pedersen, Lars

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Some Passive Damping Sources on Flooring-Systems besides the TMD

Lars Pedersen

Aalborg University
Department of Civil Engineering
Sohngaardsholmsvej 57
DK-9000 Aalborg

ABSTRACT

Impulsive loads and walking loads can generate problematic structural vibrations in flooring-systems. Measures that may be taken to mitigate the problem would often be to consider the implementation of a tuned mass damper or even more advanced vibration control technologies; this in order to add damping to the structure. Basically also passive humans on a floor act as a damping source, but it also turns out from doing system identification tests with a floor strip that a quite simple set-up installed on the floor (cheap and readily at hand) might do a good job in terms of reducing vertical floor vibrations for some floors. The paper describes the tests with the floor strip, and the results, in terms of dynamic floor behaviour, are compared with what would be expected had the floor instead been equipped with a tuned mass damper.

NOMENCLATURE

f	Floor frequency	f_1	TMD frequency	μ	Mass ratio
ζ	Floor damping ratio	ζ_1	TMD damping ratio	x	Distance from support
L	Span length	M	Modal mass	m	Mass

1. INTRODUCTION

Damping characteristics of flooring systems have a profound effect on how floors perform when excited by dynamic loads. For instance, walking loads may generate problematic resonant phenomena [1], but also vibration sources outside a building may induce vibrations in floors which are problematic. Guidelines are available suggesting damping characteristics for different types of flooring systems, but still floor vibration problems emerge from time to time.

Flooring systems of today are generally more slender than those erected several years ago, and thus more prone to react likely to walking loads. That fact that modern open-space office environments do not involve many partitions is also likely to have a bearing on the dynamic behaviour of floors, as partitions add damping to the floor. Likewise, the tendency to store information on a pc instead of in bookcases probably also has an effect on magnitudes of floor response as bookcases would contribute with damping. So a number of non-structural components can have an influence on the dynamic behaviour of floor slabs [2].

This paper is not dealing with the passive damping sources mentioned above. Instead it places focus on other types of passive damping sources on flooring systems; damping sources which are often not addressed or considered when focus is on floor vibrations.

When floor vibrations are problematic it is often because the vibrations are perceived as annoying by floor users. Often it would be a stationary person (not the walking person generating the vibrations) that would perceive vibrations as annoying. Hence, at least one stationary person (for instance a sitting person) would need to be present on the floor for someone to perceive vibrations as annoying. Measurements made on grandstands [3-4] and on test floors in laboratory environments [5-7] have proven that stationary humans act as passive damping sources, and the present paper will quantify the amount of damping added to a floor strip by humans in sitting posture.

It also turns out (from the experimental investigations reported in this paper) that there are other passive damping sources on floors that may come into play. Specifically, the paper considers how different types of chairs perform in terms of mitigating floor vibrations. The chairs themselves do not add much damping to the floor, but the paper investigates what happens when sandbags are placed in the seats of chairs. The tested chairs are rigid office chairs and swivel chairs. In tests, the sandbag mass, and the number of chairs on the floor, is gradually increased so as to explore what effect this has on the damping added to the floor.

When floor vibration problems occur, a tuned mass damper (TMD) may be useful [8], but even more advanced remedial measures (vibration control devices) have also been considered for flooring systems [9]. In order to give some perspective to the amount of damping found to be added by humans and by chairs carrying sandbags, results are compared with the expected performance of a TMD fitted to the floor strip.

Experiments and test procedures are outlined in section 2, and section 3 presents the results in terms of the damping added to the floor strip.

2. THE EXPERIMENTS

2.1 The test floor and the instrumentation

The test floor is a hollow-core concrete element pin supported at both ends. The distance between the supports of the one-way spanning element is about 11 m, and the width of the element is about 1.2 m. The weight of the element amounts to more than 5,000 kg.

As the floor-strip is pin-supported, its fundamental mode (the first vertical bending mode) is well separated from other modes of vibration, and in tests this mode is excited. It is the damping ratio of the fundamental mode which is determined in tests. This is done by bringing the element into free decaying vibrations by applying an impact load at midspan, and from recordings of floor vertical displacement response (by LVDT's positioned at floor midspan), the damping ratio of the floor is identified using the logarithmic decrement method.

Without any chairs or humans atop the test floor its undamped frequency was found to be 5.8 Hz and the damping ratio was found to be around 0.25 %cr.

2.2 Tests with chairs and humans atop the floor

Six test sequences were carried out, and they are denoted A, B, C, D, E, and F.

The first two test sequences are described below:

A. One rigid office chair atop the floor strip at midspan
B. One swivel chair atop the floor strip at midspan

In these tests, floor damping was determined with different numbers of sandbags placed in the seat of the chairs. Each sandbag had a weight of 40 kg, and after doing a test without a sandbag, first one, then two, three and finally four sandbags were placed in the seat. In the presentation of results, the sandbag weight is denoted m, and floor damping was thus determined for values of m of 0, 40, 80, 120, and 160 kg. This provides insight into how the value of m influences floor damping for the two different types of chairs. In tests with the swivel chair, a number of different swivel chairs were used so as to investigate variability in results (for m = 80 kg) from chair to chair. All swivel chairs were of the same type of construction. The swivel chairs employed in tests are perhaps 15 years old and are not provided with modern damping devices between seat and wheel frame. The wheel frames of the chairs carry five wheels. The rigid office chair is a standard four-legged office chair used at Aalborg

University in meeting rooms, whereas the swivel chair is the type used by students at their desks. A principle sketch of the two chairs is shown in figure 1.

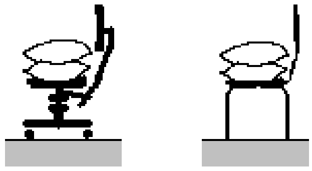

Figure 1 The swivel chair (left) and the rigid office chair (right) used in tests. The chairs are shown carrying two sandbags (m = 80 kg).

In test sequences C and D not only a single chair was used. These tests involved:

C. Up to four office chairs atop the floor strip at midspan
D. Up to four swivel chairs atop the floor strip at midspan

In these tests, three or four chairs were positioned on the floor strip at the same time, and the chairs were each carrying either 80 kg of sandbag (2 sandbags) or no sandbags. Figure 2 shows an example. The tests were made in the way that first one chair carried 80 kg (m = 80 kg), then two chairs carried 80 kg each (m = 160 kg), and then three chairs carried 80 kg each (m = 240 kg), etc. This procedure allows for investigating how floor damping is influenced when the sandbag mass is split (carried by more than one chair), which also accommodates a higher total sandbag mass than what is possible to carry by a single chair.

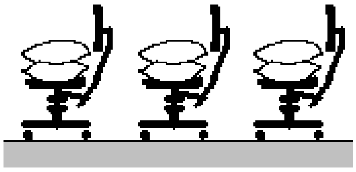

Figure 2 Side view of floor strip at midspan. Three swivel chairs each carrying 80 kg (m = 240 kg).

Test sequence E:

E. Single swivel chair atop the floor strip at various positions

In this test sequence a randomly selected swivel chair was placed at different positions on the floor strip carrying a sandbag mass of 80 kg (see figure 3), and for each position floor damping was identified. The different positions were chosen such that floor damping could be mapped as a function of the distance from floor support.

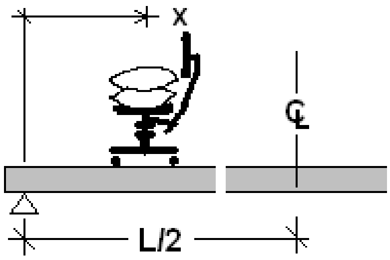

Figure 3 The swivel chair placed at a distance of x from floor support.

Test sequence F involved humans, so as to establish a reference for the damping introduced by chairs:

F. Humans sitting atop the floor strip at midspan

In this test, human sat on the floor strip with legs hanging down over the side of the floor strip as shown in figure 4. Floor damping was determined in situations were one, two and three persons sat on the floor strip.

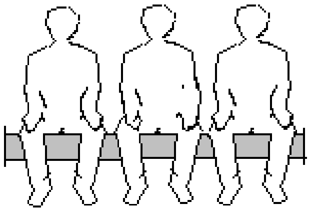

Figure 4 Side view of floor strip. Three humans sitting at floor midspan.

The individuals were asked to assume this posture during the entire phase of decaying vibrations. Each individual was weighted prior to the tests, such that the total mass (*m*) of the crowd was known. Thereby, it was possible to relate estimates of floor damping to the total mass of the crowd of people. For all test conditions, a series of free decay tests were made allowing a series of estimates of floor damping to be produced. For simplicity, the result section only presents mean values of floor damping (obtained under similar conditions).

3. RESULTS

From the floor decays, the mean value of estimates of floor damping, ζ, was calculated for different values of the mass (*m*), representing either sandbag or human mass.

3.1 Single chair on the floor (tests A and B)

Figure 5 shows estimates of floor damping obtained with different swivel chairs (solid lines) and with the rigid office chair (dashed line). For m = 0 kg the chair does not carry a sandbag. As can be seen, the positioning of sandbags on the rigid office chair does not result in a change in floor damping.

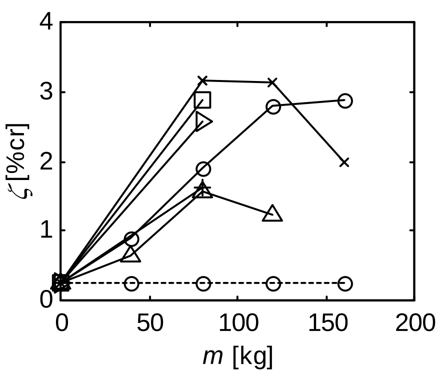

Figure 5 Variations of floor damping with sandbag mass when in seat of swivel and office chair. (solid and dashed lines, respectively)

However, this is not the case for the swivel chair. When placing sandbags in the seat of this type of chair, a significant increase in floor damping is observed. With a sandbag weight of 80 kg in the seat of one of the tested swivel chairs, the damping increases from 0.25 %cr to a value above 3 %cr (corresponding to an increase in damping of more than a factor 12). This was the observation that initiated the investigations of this paper.

As can be seen not all swivel chairs turned out to perform as well in terms of adding damping to the floor, but it is noticeable that all tested swivel chairs carrying 80 kg of sandbag increased floor damping by a factor 6 or more.

This is quite significant considering that the concrete element, atop of which the swivel chair is placed, weights more than 5,000 kg. It can be seen that in most cases floor damping increases when more sandbag weight is placed in the seat.

3.2 Several chairs on the floor (tests C and D)

Figure 6 shows results of floor damping obtained with sandbag weights of 80 kg placed in the seat of one chair (*m* = 80 kg), two chairs (*m* = 160 kg), three chairs (*m* = 240 kg), etc.

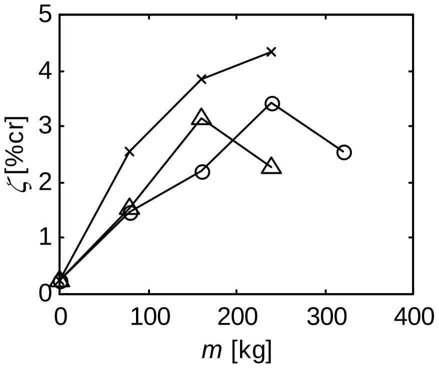

Figure 6 Variations of floor damping with sandbag mass when placed in seat of swivel chairs.

Results obtained for the rigid office chair are not shown as basically no difference in floor damping could be noticed compared with the reference case (*m* = 0 kg).

For the tests that involved swivel chairs, eight chairs were available. Among these chairs, three different combinations of chairs were used in tests (3 to 4 chairs were randomly selected for each combination/test) This explains why three ζ-m relationships are obtained.

As can be seen, generally the floor damping increases when an additional swivel chair is equipped with a sandbag mass of 80 kg. There are exceptions as in two tests a slight decline is noticed when placing 80 kg in the seat of an additional chair (3^{rd} or 4^{th} chair). It is not readily possible to explain why this occurs.

Besides from the slightly deviating results there is the tendency that when more chairs are equipped with sandbags, more damping is added to the floor.

3.3 Various positions of swivel chair (test E)

For an attached damping source it would be expected that the amount of damping that it adds to the floor depends on the location of the damping source.

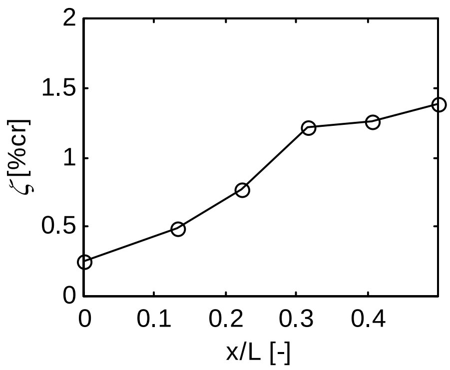

Figure 7 Variations of floor damping with location of swivel chair carrying a sandbag weight of 80 kg. (x/L = 0: pin support, x/L = 0.5: midspan).

Whether this feature is also valid for the “swivel chair with sandbag”–damper was examined for a randomly selected swivel chair and the results are shown in figure 7.

It can be seen that when the swivel chair is located right over the pin support of the floor strip, the floor damping corresponds to that of the floor without the chair present (0.25 %cr).

As the chair is moved towards midspan, floor damping increases and the chair adds most damping when positioned at midspan of the floor strip (x/L = 0.5).

These are meaningful results.

3.4 Humans on floor strip and their damping capacity (test F)

Floor damping was also identified when humans sat on the floor strip, and figure 8 shows the results (+).

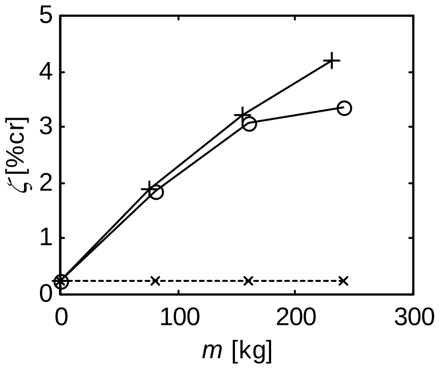

Figure 8 Floor damping measured with humans sitting on the floor (+), with sandbags in the seat of swivel chairs (o) and rigid office chairs (x).

For reference, figure 8 also shows floor damping as measured with sandbags in the seat of swivel chairs (o) and rigid office chairs (x).

It is noticeable that humans add much damping to the floor. With three persons sitting at midspan ($m \approx 230$ kg), floor damping is above 4 %cr, which is more than 16 times the damping of the empty floor.

The damping values shown for the swivel chairs are the averages of the results shown in figure 7 (for m = 80, 160, and 240 kg).

Definitely, passive damping sources such as humans and swivel chairs with sandbags contribute with much damping.

In order to provide some perspective to the damping added by humans and swivel chairs, numerical calculations were made predicting decaying floor vibrations with a TMD installed on the floor strip (instead of humans and swivel chairs). For the TMD design its frequency (f_1) and damping ratio (ζ_1) was determined from eq. 1, as suggested in [10].

$$f_1 = f/(1+\mu) \qquad \zeta_1 = (3/8 \cdot \mu/(1+\mu))^{0.5} \qquad \mu = m/M \tag{1}$$

In eq. 1, M is the modal mass of the first bending mode of the floor strip, and f is the frequency of this mode (as measured for the empty floor). For the calculations, the TMD mass (m) was assumed to be 80 kg, which is equal to the weight of two sandbags and approximately equal to the weight of a person. Using a Newmark time integration scheme, decaying floor response to an impact load was computed. Figure 9 compares the calculated decay with those measured in tests.

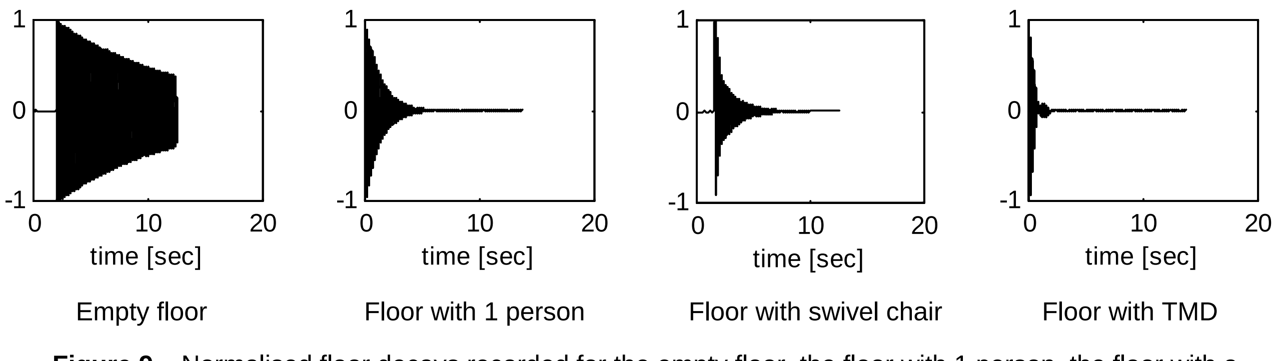

Figure 9 Normalised floor decays recorded for the empty floor, the floor with 1 person, the floor with a swivel chair carrying a sandbag weight of 80 kg, and simulated for the floor strip with a TMD.

As can be seen, the TMD adds more damping to the floor than the swivel chair carrying a sandbag weight of 80 kg. However, it can be recognised that both the swivel chair and a person sitting on the floor perform quite well in reducing floor vibrations. It should be noted that when deriving damping estimates from decays with swivel chairs on the floor, the initial oscillations were discarded (the first 5 oscillations right after the impact). In the discarded time window, oscillations decayed more rapidly (for some chairs) than in the remaining part of the decay in which damping was fairly constant.

4. CONCLUSION AND DISCUSSION

The investigations of the paper quantified how chairs carrying sandbags influenced damping characteristics of a floor strip with a frequency of 5.8 Hz. It was found that swivel chairs with sandbags in their seats added much damping to the floor strip (to its fundamental mode, first vertical bending mode), and that the "swivel chair with sandbag"-damper added most damping when located at midspan of the floor strip. It was also shown that persons sitting on the floor strip added much damping, and that floor damping depends on the size of the crowd of people present atop the floor.

The damping added by an optimally tuned TMD with a mass of 80 kg was shown to be higher than the damping added by a single person sitting at midspan and higher than the damping added by the swivel chair with 80 kg of sandbag in the seat. Nevertheless, the results indicate that passive damping sources such as humans and swivel chairs carrying humans can add much damping to the floor.

The TMD has the advantage that it can be tuned and targeted to solving a specific vibration problem, basically for any floor frequency. This is not the case for the swivel chair carrying sandbags. Its performance in mitigating floor vibrations for a specific floor is by default dictated by the mechanical characteristics of the chair having fixed characteristics. As long as the mechanical characteristics of the chair are unknown (and they are unknown to the author of this paper) it is quite difficult to predict how the swivel chair would perform in mitigating vibrations on a floor with a natural frequency different from that used in the present tests. It might perform even better or it might perform worse on other floors. Empty floor modal mass and damping would also be parameters influencing the damping capacity of swivel chair(s), but this is also the case for the TMD.

In any case it is not expected that swivel chairs will be used as a permanent solution for solving vibration problems in flooring-systems (for a number of reasons, although the chairs are cheap and readily at hand), but they might, for some floors, be considered for use as a temporary remedial measure taking the top of excessive vibrations until permanent and reliable solutions are found. At least the results of the investigations suggest that the swivel chair has an inherent damping capacity that can be brought into play when loaded by sandbags, which might be useful to have in mind.

Also it is considered useful to have in mind that floor damping (and floor frequency) is not a constant, but a value which will change over time depending on the number of stationary people present on the floor.

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